Digital Imaging and Communications in Medicine (DICOM)

Supplement 84: Clarification of US Region Calibration Flags

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DICOM Standards Committee

1300 N. 17th Street, Suite 1847

Rosslyn, Virginia 22209 USA

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Foreword

This Supplement clarifies the definitions of ultrasound image regions, including calibration for intersecting regions.

This document is a Supplement to the DICOM Standard. It modifies the following parts of the published DICOM Standard:

PS 3.3 - Information Object Definitions

Introduction - will not appear in final standard

Introduction

SCOPE AND FIELD OF APPLICATION

This Supplement clarifies the meaning of pixel component calibration for intersecting US Calibration Regions. The US Region Calibration Module specifies that intersecting regions can each be specified as Transparent or Opaque. It specifies, “If the region is transparent, then measurements may be done on regions underneath this region.” However, the meaning of this flag is ambiguous and does not fit the intended role.

First, the definition implies that this flag applies to both 2D scaling and pixel component calibration whereas it should only apply to the latter. Also, the terms “Transparent” and “Opaque” imply visibility of the image, but the flag actually defines whether the pixel component calibration of one region shares another region’s bit planes in an intersecting area. This Supplement thus proposes to replace the terms “Transparent” and “Opaque” with “**Region pixels are low priority** ” and “**Region pixels are high priority** ” respectively.

Another issue is that the recommended reference pixel locations should vary depending on the type and spatial organization of the data within the region but the Standard does not currently convey this. Changes are proposed so that the recommended locations are now properly based on these attributes.

Finally, the Standard is not very clear regarding the manner in which the directionality of 2D physical scaling should be conveyed, particular for Doppler data. This Supplement proposes to resolve this by giving explicit meaning to the polarity of the Physical Delta value used to convey velocity and frequency values.

Changes to NEMA Standards Publication PS 3.3-2003

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

Modify PS3.3, Table C.8-16 to include references to a new normative section clarifying the directionality for the Physical Delta X and Physical Delta Y Attributes.

Table C.8-16
US FRAME OF REFERENCE MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Physical Delta X	(0018,602C)**{** XE "(0018,602C)" **}**	1	The physical value increments per positive X pixel increment. The units are as specified in the ~~Physical units data element~~ **Physical Units X Direction (0018,6024)**. **See C.8.5.4.1.4 for further explanation.**
Physical Delta Y	(0018,602E)**{** XE "(0018,602E)" **}**	1	The physical value increments per positive Y pixel increment. The units are as specified in the ~~Physical units data element~~ **Physical Units Y Direction (0018,6026)**. **See C.8.5.4.1.4 for further explanation.**

The following modifications to the C.8.5.4.1. sub-sections include information regarding both the C.8.5.4, US Frame of Reference Module Attributes and the C.8.5.5, US Region Calibration Attributes. This means that these sub-sections should be moved to those describing the US Region Calibration Attributes. This is already proposed in CP433: Retire Ultrasound Frame of Reference, so these sub-sections have not been moved in this Supplement. If CP433 is rejected for some reason though then these sub-sections should still be moved to those for US Region Calibration, and the corresponding references in Tables C.8-16 and C.8-17.

Alter PS3.3, C.8.5.4.1.1, to clarify that the screen coordinates are offset to the image coordinate origin convention of (1,1) at most upper left corner of image.:

C.8.5.4.1.1 Region Location Min x_0, Region Location Min y_0, Region Location Max x_1 , Region Location Max y_1

The**se attributes specify** ~~bounds of a rectangle specifying~~ the location of the region, Region Location Min x_0 (0018,6018)**{**xe "(0018,6018)"**}**, Region Location Min y_0 (0018,601A)**{**xe "(0018,601A)"**}**, Region Location Max x_1 (0018,601C)**{**xe "(0018,601C)"**}**, Region Location Max y_1 (0018,601E) **expressed as offsets to the pixel coordinates{**xe "(0018,601E)"**}**. The upper left corner of the entire image is x=0,y=0 and the lower right corner is x=image width - 1, and y=image length - 1. Thus, a region will be specified as within these bounds. Where x_0,y_0 is the coordinate of the upper left corner of the region and x_1,y_1 is the coordinate of the lower right corner of the region.

Alter PS3.3, C.8.5.4.1.3, so that the recommended reference pixel locations vary depending on the type and spatial organization of the data within the region. Also, add figures that illustrate typical reference pixel locations:

C.8.5.4.1.3 Reference Pixel x_0 and Reference Pixel y_0

This coordinate pair, Reference Pixel x_0 (0018,6020), Reference Pixel y_0 (0018,6022) defines the location of a virtual "reference" pixel. **This** reference pixel **location** is used to tie the image's pixel coordinate system to the physical coordinate system. For example, the reference pixel could be defined where a depth of zero centimeters occurs in the 2D image, or it could define where the baseline (i.e.: zero frequency) resides in a spectral display. The reference pixel location is the relative offset from the **Region Location Min x_0 (0018,6018) and Region Location Min y_0 (0018,601A)** ~~**region location**~~, not ~~**necessarily**~~ the image origin. The location is not required to be within the region or even within the image boundary. For this reason, the ~~**Reference Pixel Location**~~ **Reference Pixel x_0 and Reference Pixel y_0 values** can be positive or negative.

~~**Recommended locations are:**~~

- ~~**Sector - Skin line**~~
- ~~**Linear - Skin line left corner**~~
- ~~**Doppler Spectral - Baseline left**~~
- ~~**M-Mode - Skin line left**~~
- ~~**Physio - Baseline left (where baseline = 0)**~~

The reference pixel location varies depending on the type and spatial organization of the data within the region.

C.8.5.4.1.3.1 2D - Tissue or Color Flow

Tissue data is tissue echo intensity displayed as grayscale. The Region Data Type (0018,6014) value is 0001H (Tissue). Color flow is Doppler signal displayed as color and encoded as some function of Doppler magnitude and velocity of blood flow or tissue motion. The Region Data Type value is 0002H (Color flow). For 2D, the Region Spatial Format (0018,6012) is 0001H (2D), meaning that the region is a tomographic image. For such 2D regions the reference pixel location is typically at the center of the transducer face on the tissue-transducer interface (skin line).

Figure C.8-1 shows 2D attribute values of reference pixel location along with Region Location Min and Region Location Max. for 2D–Tissue and 2D–Color Flow Regions:

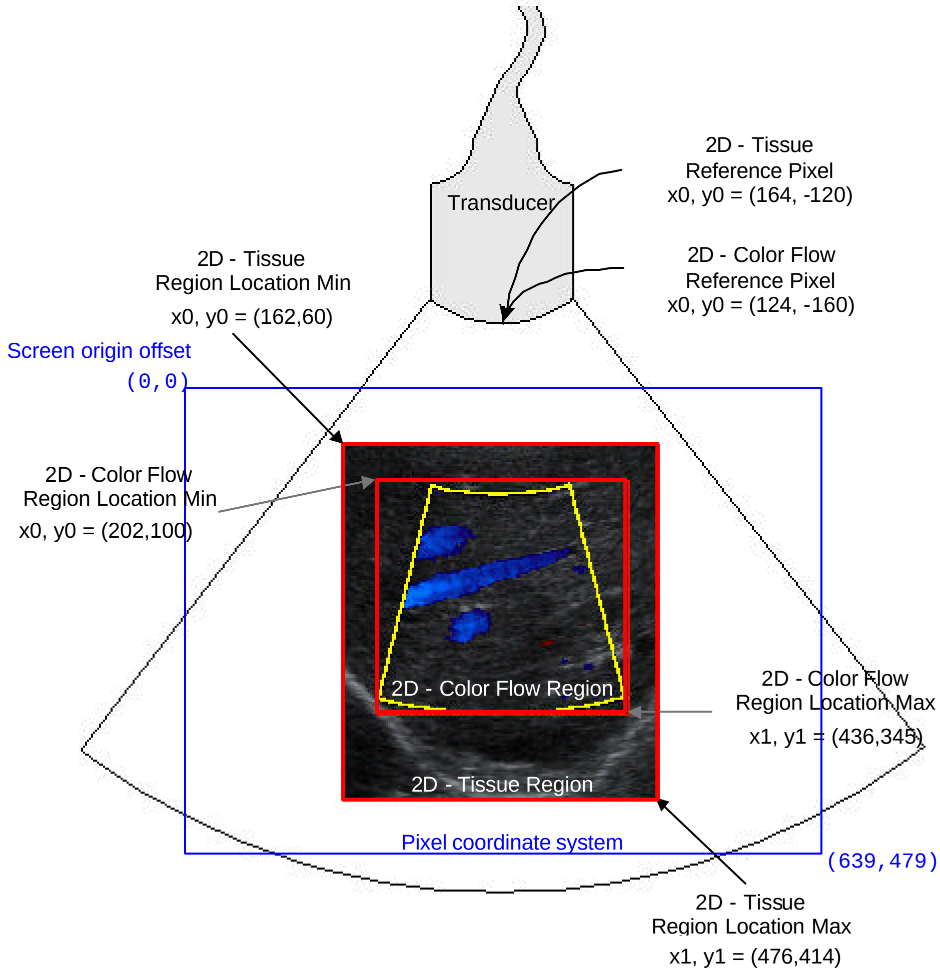

Figure C.8-1
2D Regions with Reference Pixel

Both the 2D regions–Tissue and Color Flow–share the same physical location at the skin line but the reference pixel location values (Reference Pixel x_0 and Reference Pixel y_0) are relative to their respective region origins at the skin line.

C.8.5.4.1.3.2 Spectral - CW or PW Doppler or Doppler Trace

Spectral Doppler is the time varying magnitude of Doppler signal as function of frequency. Region Data Type (0018,6014) value is 0003H (pulsed wave Doppler) or 0004H (continuous wave Doppler). Spectral Doppler regions display the magnitude of Doppler signal with frequency or velocity as the vertical dimension and time as the horizontal dimension. Spectral Doppler regions have a Region Spatial Format (0018,6012) of 0003H (Spectral). The time dimension for the Region Spatial Format displays horizontally with data scrolling toward the left or sweeping toward the right. The reference pixel location is the pixel in the frame where:

- **the time is the time of frame capture (i.e. the time origin for the frame)**
- **and on the Doppler Baseline (i.e. where the velocity and frequency are zero).**

Figure C.8-2 shows an example of reference pixel locations in an image with both a Tissue and a scrolling Spectral (CW or PW Doppler) Region. The user adjusts the depth and position of the Doppler sample volume. The system annotates the sample volume position on the 2D region and specifies the location in Doppler Sample Volume X Position (0018,6039) and Doppler Sample Volume Y Position (0018,603B).

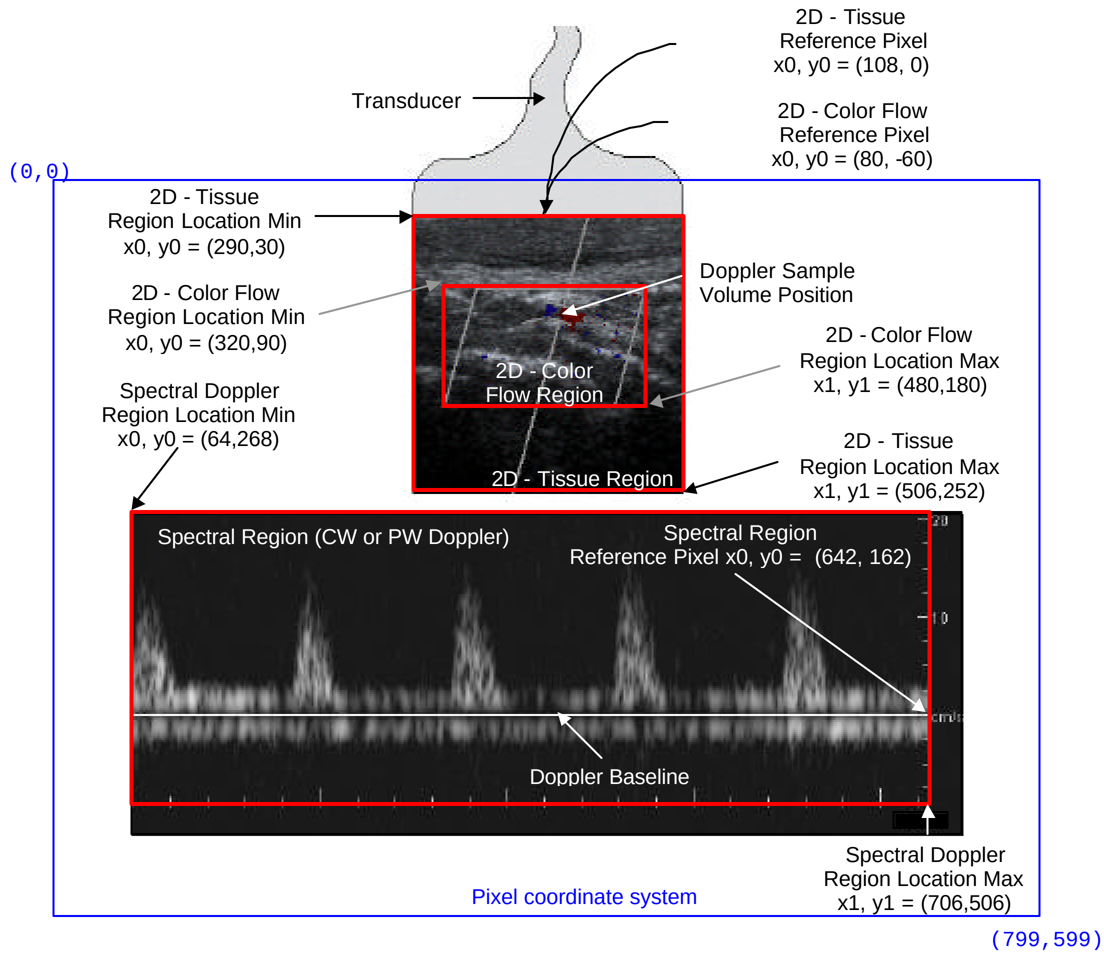

Figure C.8-2
2D & Doppler Regions with Reference Pixel

The scrolling Spectral Region reference pixel location specifies the horizontal location at the time of the current image frame. Data to the left of this location in the Spectral Region was acquired in the past. Because time increases to the right, the Physical Delta X (0018,602C) for this Region is positive. To specify the location of the most recent data the Reference Pixel x_0 specifies the time of acquisition, and the Ref. Pixel Physical Value X (0018,6028) specifies the reference time to be zero. The Physical Units X Direction (0018,6024) is seconds. For an explanation of how to handle sweeping regions refer to C.8.5.4.1.3.7 Treatment of Sweeping Regions.

The Ref. Pixel Physical Value Y (0018,602A) value specifies the baseline where velocity or frequency are zero. Typically spectral Doppler regions display positive velocity (cm/Sec) or frequency shift (Hz) above the baseline. This indicates flow toward the transducer face. Negative velocity or frequency information is displayed below the baseline. This indicates flow away from

the transducer face. The Physical Delta Y (0018,602E) value is therefore negative because vertical coordinates increment downwards.

C.8.5.4.1.3.3 M-Mode - Tissue or Color Flow

M-Mode is tissue or color flow with a Region Spatial Format (0018,6012) of 0002H (M-mode). The vertical reference pixel location is the transducer face.

The horizontal reference pixel location is the pixel in the frame where:

- the time is the time of frame capture (i.e. the time origin for the frame)
- and zero depth from the transducer face

Figure C.8-3 shows an example of reference pixel locations for 2D Tissue and M-Mode Regions within the same image frame. The system annotates the sample line position on the 2D tissue region and specifies its position with the TM-Line Position attributes (0018,603D), (0018,603F), (0018,6041), and (0018,6043).

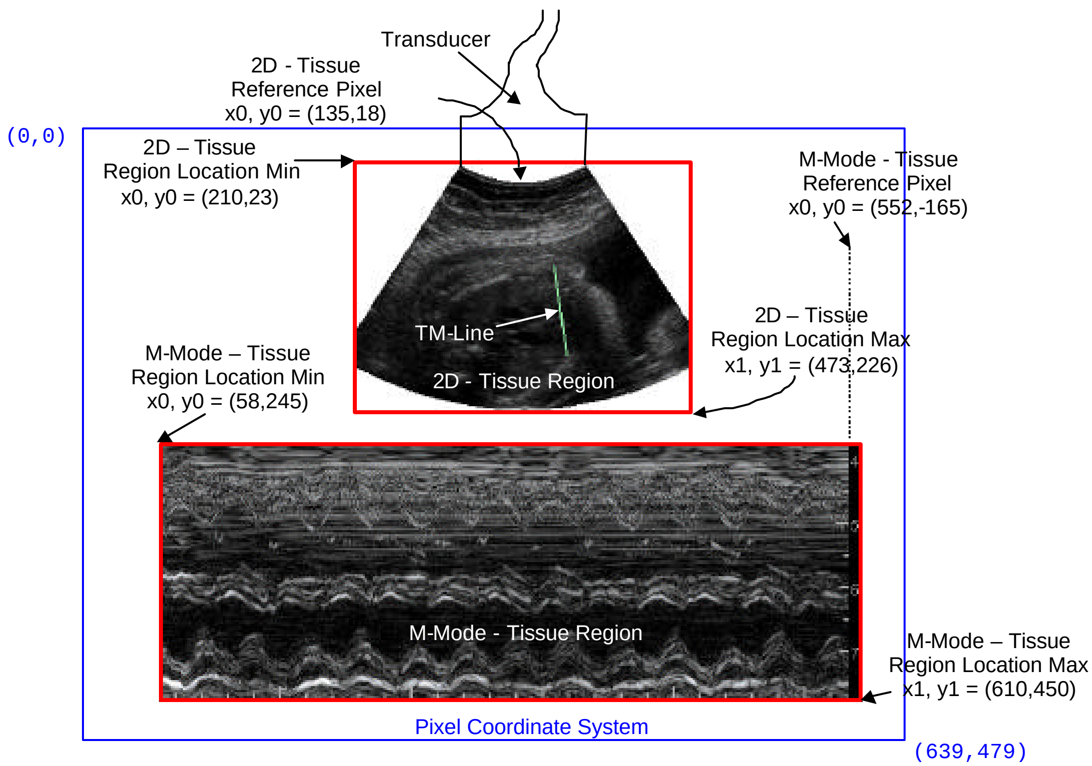

Figure C.8-3
2D & M-Mode Regions with Reference Pixel Example

The physical length of the TM-Line corresponds directly to the physical height of the M-Mode Region. The M-Mode region's Reference Pixel y0 can be used to calculate the depth of the M-Mode region and facilitate depth measurements. In this example the M-Mode Region Reference Pixel y0 has a negative value corresponding to the distance between the face of the ultrasound probe and the TM-Line starting point. Note that the negative offset in pixel units is determined using the pixel height-width scaling of the M-Mode - Tissue Region as this could differ from the scaling of the 2D – Tissue Region (as it does in this example).

C.8.5.4.1.3.4 Waveform - ECG, Phonocardiogram and Pulse Traces

Waveforms are traces with a Region Spatial Format (0018,6012) value of 0004H (Waveform). The Reference Pixel x_0 (0018,6020) specifies the time origin as the time of frame capture. There is typically no baseline position for ECG traces; the Reference Pixel y_0 (0018,6022) is arbitrary.

Figure C.8-4 shows an example of reference pixel location for 2D Tissue, M-Mode, and ECG Waveform Regions within the same image frame:

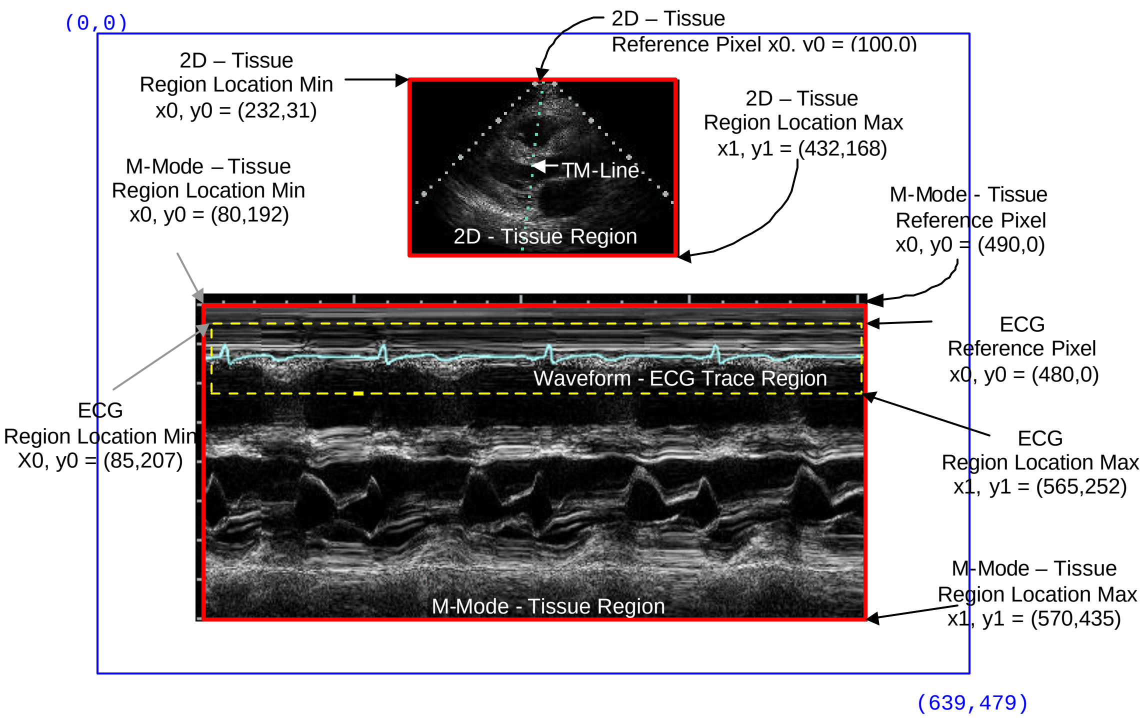

Figure C.8-4
2D, M-Mode, & Waveform Regions with Reference Pixel

C.8.5.4.1.3.5 Waveform - Doppler Mode, Mean and Max Trace

Doppler Traces have a Region Spatial Format (0018,6012) value of 0004H (Waveform) and a Region Data Type value of 0005H (Doppler Mean Trace), 0006H (Doppler Mode Trace) or 0007H (Doppler Max Trace). The Reference Pixel x_0 (0018,6020) specifies the time origin as the time of frame capture. The Reference Pixel y0 (0018,6022) is the Doppler Baseline position (zero velocity / frequency position).

C.8.5.4.1.3.6 Graphics Spatial Formats

For regions with Region Spatial Format (0018,6012) value of 0005H (Graphics) the reference pixel location has no meaning.

C.8.5.4.1.3.7 Treatment of Sweeping Regions

Time-based display of data may scroll the acquired data from a fixed horizontal location to the left. Alternatively, sweep-based display increments the horizontal location of the acquired data, overwriting previously acquired data to the right. When the horizontal location corresponding to zero time has completely swept over the older data, writing wraps from the left of the region. Thus, sweep-based displays have a time discontinuity. The measurement of time intervals across

the discontinuity require special treatment. The time interval between two points across the discontinuity is equal to the region's time width minus the point separation. The sweeping area can be treated as a single region. The Reference Pixel x0 should indicate the time origin for the multi-frame image, which will be the location of the sweeping region's discontinuity line for the first frame of the multi-frame image. In order to specify that this is actually the location of the discontinuity line, the Ref. Pixel Physical Value X (0018,6028) must be set to 0 seconds. This indicates that this location corresponds to the time at which the first frame was acquired.

It is useful to be able to calculate the location of the discontinuity line for subsequent frames of a multi-frame image. This is necessary if one is to determine whether two points are on opposite sides of the discontinuity line and also to correctly calculate the difference in time between such points. The x-axis location of the discontinuity line, x, for a given frame number, y, can be calculated from the Reference Pixel x0, x0, the Reference Pixel x1, x1, the time offset for frame y, t, (determined from the Frame Time Vector (0018,1065) or Frame Time (0018,1063)) and the Physical Delta X (0018,602C), p_x, as follows:

$$x = x0 + \text{modulus}((t / p_x) / (x1 - x0))$$

Alternatively, two regions can be used, one on each side of the time discontinuity. Figure C.8-5 shows the use of two regions. Note that the two region approach is not valid for multi-frame images, as the same region scaling must apply to all the frames.

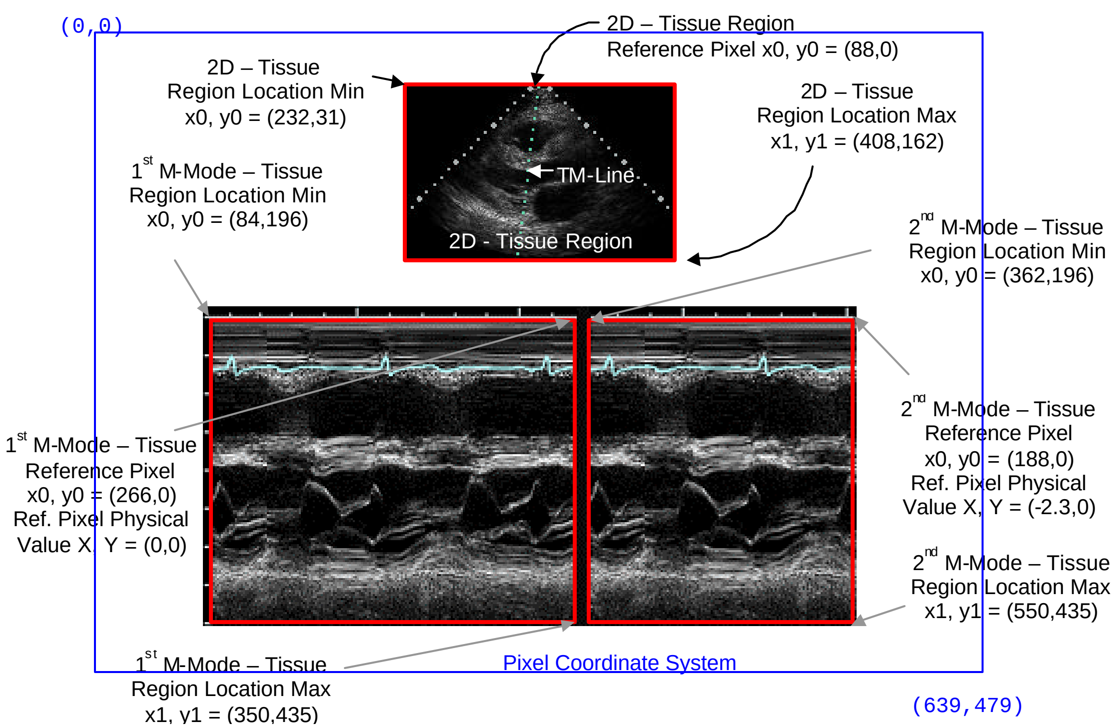

Figure C.8-5
Sweep Example using Two Regions

The two region approach may also be used in Doppler or physiological sweeping regions.

Time-based display of data may also be a combination of sweeping and scrolling. Sweep-based display is used at the start of acquisition, incrementing the horizontal location of the acquired data from left to right. After the horizontal location corresponding to zero time has completely swept to the right hand limit of the region, writing scrolls to the left from the right hand limit rather

than wrapping from the left. A single region should be specified when this combination of behavior is used. The ~~x-~~axis (zero time) location, x, for a given frame number, y, can be calculated from the Reference Pixel x0, x0, the Reference Pixel x1, x1, the time offset for frame y, t, (determined from the Frame Time Vector (0018,1065) or Frame Time (0018,1063)) and the Physical Delta X, p_x, as follows:

$$X = \mathrm{Min}\ (\ x0 + (t\ /\ p_x),\ x1)$$

Add a new section PS3.3, C.8.5.4.1.4 that clarifies the directionality issue for Physical Delta values:

C.8.5.4.1.4 Physical Delta X And Physical Delta Y

The Physical Delta X (0018,602C) is the physical value increment per positive X pixel increment, which is left to right. The Physical Delta Y (0018,602E) is the physical value increment per positive Y pixel increment which is top to bottom.

> **Note: When displaying Doppler data, ultrasound applications typically display the Doppler strip horizontally, with data sweeping (moving time origin) from left (oldest) to right (newest) or scrolling (static time origin) from right to left. The default display of positive velocity values normally indicates flow toward the transducer; negative velocity values indicate flow away from the transducer. In this case a negative Physical Delta Y is required to specify that the direction of positive velocities or frequencies is upward.**

Modify PS3.3, Table C.8-17 to include references to a new normative section clarifying the directionality for the Physical Delta X and Physical Delta Y Attributes:

Table C.8-17
US REGION CALIBRATION MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
>Physical Delta X	(0018,602C)**{** XE "(0018,602C)" **}**	1	The physical value increments per positive X pixel increment. The units are as specified in the ~~physical units data element~~ **Physical Units X Direction (0018,6024)**. **See C.8.5.4.1.4 for further explanation.**
>Physical Delta Y	(0018,602E)**{** XE "(0018,602E)" **}**	1	The physical value increments per positive Y pixel increment. The units are as specified in the ~~physical units data element~~ **Physical Units Y Direction (0018,6026)**. **See C.8.5.4.1.4 for further explanation.**

Modify Section C.8.5.5.1.3 of PS 3.3:

C.8.5.5.1.3 Region Flags

Region Flags (0018,6016)**{** XE "(0018,6016)" **} specify characteristics of US Regions~~for special handling of the region~~.**

Bit 0 of the Region Flags specifies the relative priority of the pixel component calibration specified by an US Region in the case where the US Region intersects with other US Regions. The calibration supplied by one or more of the regions may not be valid in the area that they intersect.
{ XE "(0018,6044)" }Enumerated Values for Bit 0 (lsb) ~~**Transparency**~~:

1 = ~~**Transparent**~~ **Region pixels are low priority**
0 = ~~**Opaque**~~ **Region pixels are high priority**

~~**If the region is transparent, then measurements may be done on regions underneath this region. This most useful for ECG overlays region overlapping with a 2D region.**~~

A high priority region overwrites data of a low priority region when they overlap, thus invalidating any pixel component calibration specified for a low priority region. pixel component calibration of overlapping regions of the same priority is indeterminate where they overlap. Figure C.8-6 **shows an example of intersecting regions.**

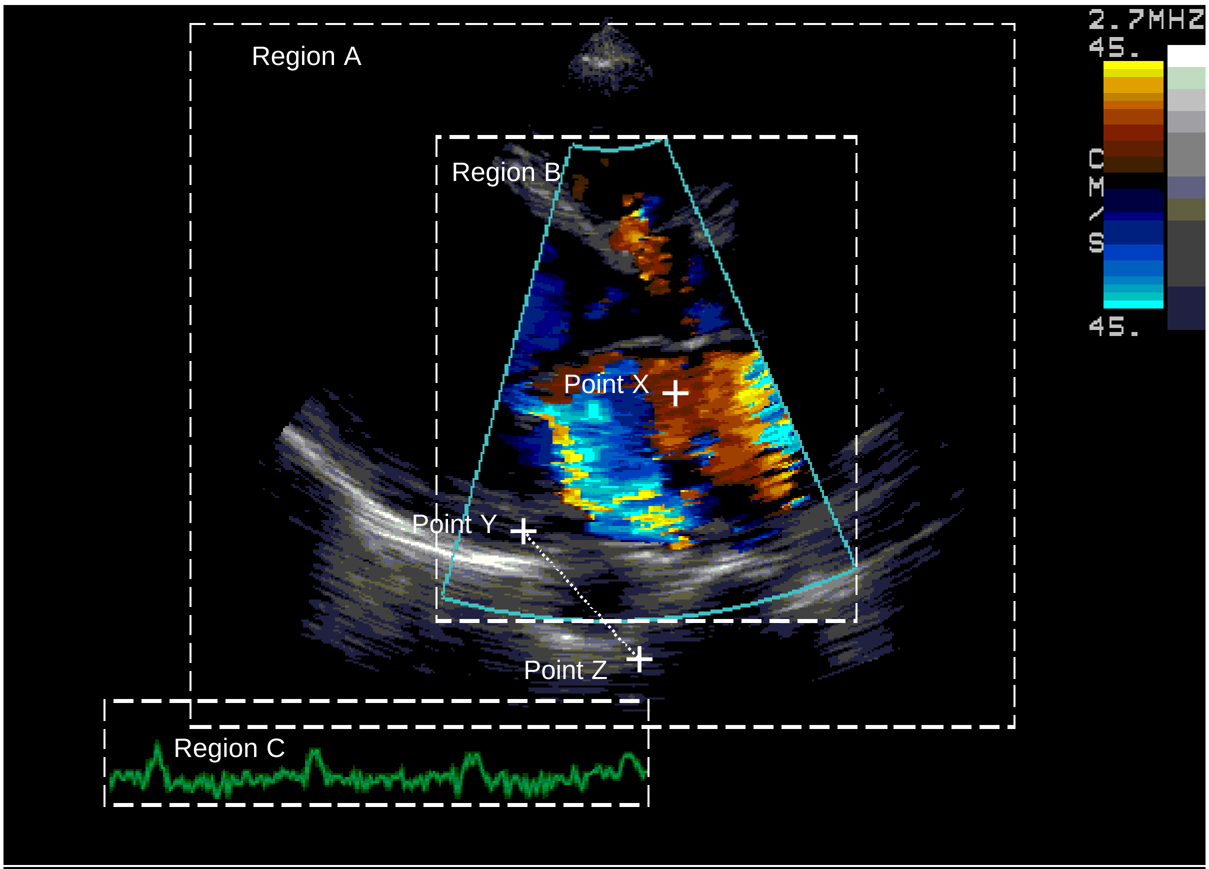

Figure C.8-6

Intersecting Spatial Format Regions and Overlapping Measurement

In this example, Region B is Color Flow while Region A is Tissue Echo. If Region B Color Flow values share the same bit planes as Region A Tissue Echo values, then it is indeterminate whether a pixel in this region is a Color Flow pixel or a Tissue Echo pixel. Since the pixels of the Color Flow region overwrite those of the Tissue Echo region, the Region Flag of the Tissue Echo region is assigned low priority and the Region Flag of the color region is assigned high priority. This means that if both the Tissue Echo and Color Flow regions define pixel component calibration that only the calibration specified by the Color Flow region can be applied to the pixel data value at Point X.

The measurement in Figure C.8-6 **is a line between Point Y and Point Z. Both points are in Region A so the distance between them can be calculated using the Region A scaling (assuming that Region A defines both the Physical Units X Direction and Y Direction as being cm). If the points are in Region B, and hence also in Region A, it is still possible to calculate the distance because the region scaling is identical in both regions. The lower priority of Region B only applies to its pixel component calibration, not its X and Y direction scaling.**

Enumerated Values for Bit 1 Scaling Protection:

1 = Protected

0 = Not Protected

Ultrasound systems should set this to 1 if the image is scaled automatically by the ultrasound system. If the image is frame-grabbed and scaling is not available then it should be set to 0. If the region is protected, the region can not be manually rescaled. That is the data defined by the region calibration Module can not be overridden by a reader of that image.

Enumerated Values for Bit 2 Doppler Scale Type:

1 = Frequency

0 = Velocity

Valid for PW and CW regions only. Indicates which type of ~~d~~**D**oppler scale is used.

Bit 3-31 Reserved for future use, shall be set to zero.

Add the following text to C.8.5.5.1.4 Pixel Component Organization

C.8.5.5.1.4 Pixel Component Organization

The Pixel Component Organization (0018,6044)**{** XE "(0018,6044)" **}** provides an Enumerated Value describing ~~**how**~~ the components of a pixel ~~**can be described**~~. The absence of this data element means that pixel component calibration does not exist for this region. ~~**Where**~~**Enumerated Values are**:

0 = Bit aligned positions
1 = Ranges
2 = Table look up

Other values are reserved for future use.

Pixel Component Organization defines the way in which the composite pixel values are mapped into real world values with physical units, as illustrated in

Figure C.8-7**.**

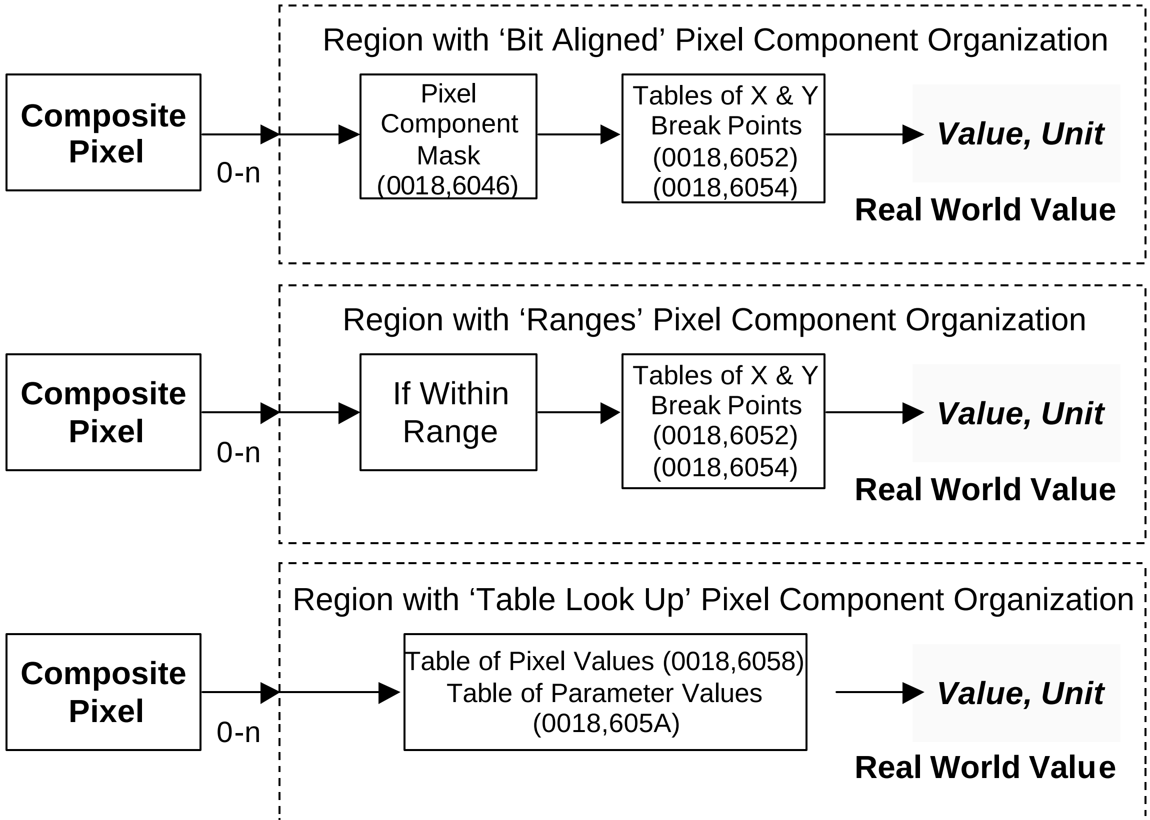

Figure C.8-7
Pixel Component Calibration

An example of Component Calibration for an ultrasound image is shown in Figure C.8-8.

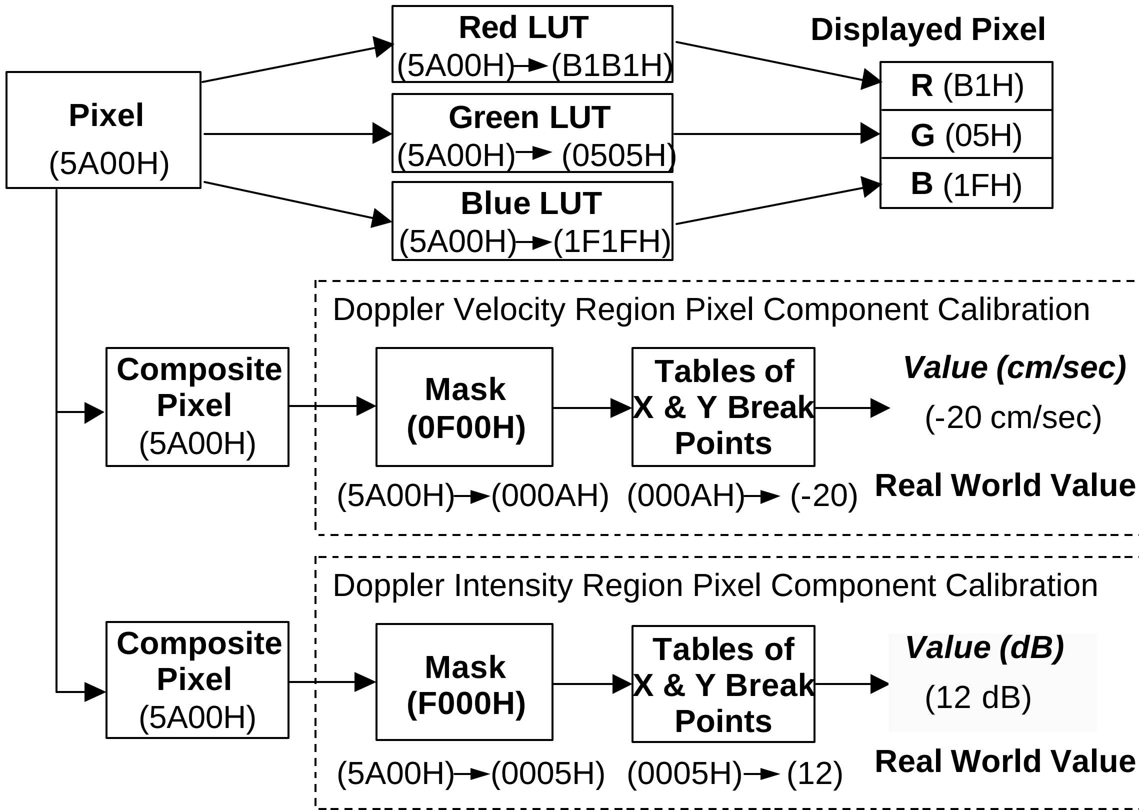

Figure C.8-8
Pixel Component Calibration Example

In this example, some pixels lie within two Regions. One Region specifies pixel component calibration for Doppler velocity values. The second Region specifies pixel component calibration for Doppler magnitude. A particular Pixel Data (7FE0,0010) value will thus map to a displayed value, a Doppler velocity and magnitude value.

The example has a Palette Color Photometric Interpretation with 16 Bits Allocated and Bits Stored per sample. The Palette Color Lookup Tables also have 16 bits for each entry. The fact that the example has just one sample per pixel means that each composite pixel value is identical to the single Pixel Data value. An example Pixel Data value is shown in brackets along with the output values resulting from each step where it is processed.

The Pixel Data value is mapped to red, green, and blue values from the supplied Palette Color Lookup Tables before being displayed. The display device supports 8 bits per sample and thus requires the scaling of the output values from the 16 bit per entry LUTs.

The Doppler Velocity Region maps each pixel value in the Region to the Doppler velocity. The Pixel Component Organization (0018,6044) has a value of zero, indicating bit aligned positions with a bit mask. The Pixel Component Mask (0018,6046) specifies that the least significant 4 bits of the most significant byte convey the Doppler velocity of each pixel. The Pixel Component Physical Units (0018,604C) are cm/sec, and the Pixel Component Data Type (0018,604E) indicates color flow velocity. The Table of X Break Points (0018,6052) and Table of Y Break Points (0018,6054) map each masked composite pixel value to a Doppler velocity value in cm/sec.

The Doppler Magnitude Region maps each pixel value in the Region to the Doppler magnitude. The Pixel Component Organization (0018,6044) has a value of zero, indicating bit aligned positions with a bit mask. The Pixel Component Mask (0018,6046) specifies that the most significant 4 bits of the most significant byte convey the Doppler magnitude of each pixel. The Pixel Component Physical Units (0018,604C) is set to dB, and the Pixel Component Data Type (0018,604E) indicates color flow magnitude. The Table of X Break Points (0018,6052) and Table of Y Break Points (0018,6054) map each masked composite pixel value to a Doppler magnitude value in dB.

Correct the wording of the last sentence of C.8.5.5.1.9 Table of X Break Points and Table of Y Break Points.

C.8.5.5.1.9 Table of X Break Points and Table of Y Break Points

Table of X Break Points (0018,6052)**{**xe "(0018,6052)"**}** and Table of Y Break Points (0018,6054)**{**xe "(0018,6054)"**}** are individual arrays of coordinates which interpreted together are used to create a piecewise linear curve. Each X value from the Table of X Break Points is matched with the corresponding Y value from the Table of Y Break Points yielding an (X,Y) coordinate. The set of (X,Y) coordinates describes a piecewise linear curve mapping the value of a pixel component to its actual physical value (in units defined in Pixel Component Physical Units data element (0018,604C)**{**xe "(0018,604C)"**}**).

The X direction on the curve has no units, and represents actual pixel component values. If the Pixel Component Organization (0018,6044)**{**xe "(0018,6044)"**}** is "Bit aligned positions", and the width of the Pixel Component Mask is *n* bits then the X coordinates are in the range 0 through $2^{n}-1$. If the Pixel Component Organization is *Ranges*, then the X coordinates are in the range 0 through $2^{\text{number of bits in the composite pixel}} - 1$.

Note: The X value is NOT relative to the Pixel Component Range Start (0018,6048)**{**xe "(0018,6048)"**}**. Not all possible X values in the range need be covered by the curve.

For any pixel component value in the range of the curve described by this table, the corresponding Y value is the actual physical value for that pixel, in units specified in the Pixel Component Physical Units data element (0018,604C)**{**xe "(0018,604C)"**}**. If the pixel component value is NOT within the range of specified X values for the curve, then no pixel calibration is defined by this region. It may be possible for pixel calibration to be defined by other spatial regions ~~underneath~~ **intersecting** this one~~**, if Region Flags (0018,6016){xe "(0018,6016)"} indicates this region is Transparent**~~**.**

Modify the labels for all existing Figures in section C.8 to reflect the fact that the new Figures with labels C.8-1, C.8-2, C.8-3, C.8-4, C.8-5, C.8-6, C.8-7 and C.8-8 have been added. The following existing Figures need to be relabeled:

C.8-1 in section C.8.7.3, Figure C.8-2 in section C.8.7.4.11, Figure C.8-3 and C.8-4 in section C.8.7.5.1.2, Figure C.8-5 in section C.8.11.1.1.1, Figure C.8-6 and Figure C.8-7 in section C.8.11.4.1.1.